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LIQUID INFLOW TO
A BAFFLED CYLINDRICAL TANK
DURING WEIGHTLESSNESS

by John V. Staskus

Lewis Research Center

Cleveland, Ohio 44135

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SUMMARY

An experimental investigation was conducted in which the behavior of liquid inflow to a cylindrical tank containing inlet baffles was observed during weightlessness. A single tank radius (2 cm), inlet radius (0.2 cm), and liquid (ethanol) were used. The inlet end of the tank was hemispherical with a 30° convergent inlet. All the baffle configurations tested were cylindrically symmetric and mounted coaxially with the tank within the hemispherical end. Both stable and unstable inflow behavior were observed using each baffle. It was found that, depending on which of the baffles was used, the critical inflow velocity at which a transition to unstable inflow began was from 2.5 to 12 times greater than the corresponding velocity in an unbaffled tank.

INTRODUCTION

Liquid transfer to and from containers in weightlessness will be an important activity of future space missions. Vehicle propellant tanks will need refueling and life support systems will need to be replenished periodically. The design of such systems requires a knowledge of the fluid behavior in tanks during both inflow and outflow so that draining and refilling them may be accomplished quickly and effectively.

A number of investigations conducted in the Lewis Research Center's Zero Gravity Facilities have studied the inflow phenomenon to unbaffled cylindrical tanks. Inflow to a cylindrical tank with a concave elliptical end is discussed in reference 1. References 2 and 3 discuss inflow to initially empty, hemispherically ended, cylindrical tanks of various diameters with different size inlets. References 4 and 5 deal with inflow to similar tanks which contained some liquid over the inlet at initiation of inflow. For an initially empty tank, it was found that stable and unstable inflow velocities could be

delineated by a Weber number of 1.5 based on the inlet radius and the average fluid inflow velocity at the inlet.

The Weber number criterion developed in reference 5 for the critical inflow velocity can be used to calculate the minimum time required to fill a tank in weightlessness. Consider a 457-centimeter (15-ft) diameter, 1829-centimeter (60-ft) long, hemispherically ended liquid-hydrogen tank with a 23-centimeter (0.75-ft) diameter inlet. The maximum inflow velocity to the initially empty tank for which the liquid-vapor interface will remain stable is 3.11 centimeters per second. Beginning with this velocity and increasing it according to the criterion developed in reference 5, the time required to fill the tank will be approximately 20 hours. Such a waiting period may often be excessive. In an effort to decrease the filling time, baffles over the tank inlet could be used to allow higher inflow velocities while maintaining a stable liquid-vapor interface. Reference 6 reports the results of a study conducted using spherical baffles inside of a spherical tank. The effect of the baffle was to allow increases in the inflow velocity of five times and greater depending on the initial volume of liquid contained in the tank.

Since no data were available for inflow to a cylindrical tank containing inlet baffles in a weightless environment, the present study was initiated. The purpose of the program was to determine the maximum inflow velocity for which the filling process remained stable for each of eight inlet baffle configurations. The experiments, using anhydrous ethanol as the test fluid, were limited to a single tank and inlet size, 2 centimeters and 0.2 centimeter in radius, respectively. The tests were conducted in the Lewis 2.2-Second Zero-Gravity Facility.

APPARATUS

The investigation was conducted in the Lewis 2.2-Second Zero-Gravity Facility. A description of the facility and test procedure can be found in the appendix.

Experiment Tank and Liquid

The experiment tank used was a 4-centimeter-inside-diameter, hemispherically ended cylinder machined from cast acrylic rod and polished to optical clarity. The inlet was of a 30° convergent design and had a 0.4-centimeter diameter at the tank entrance. The tank was vented to the atmosphere through a 0.8-centimeter-diameter port on the longitudinal axis of the tank opposite the inlet.

Anhydrous ethanol was the liquid used for the experiments. It had an essentially 0° static contact angle with the acrylic tank wall in order to duplicate the contact angle of most spacecraft liquids on tank materials. A small amount of dye was added to the

ethanol to improve the photography. Tests had determined that the addition of the dye had no measurable effect on the fluid properties.

Baffles

Plain disk baffles. - The plain disk baffles (fig. 1(a)) were simple circular disks (stainless steel and fluorocarbon resin), 1.6 centimeters in diameter and 0.08 centimeter thick. They were located 1 centimeter from the inlet and, like all of the baffles, were mounted coaxially with the tank cylinder. The mounting was accomplished using three 0.19-centimeter-diameter, thin wall, tubular spacers. The fluorocarbon resin disk was used to determine whether the increased contact angle of the anhydrous ethanol on the baffle material significantly altered the baffle's performance. The contact angle of ethanol on the fluorocarbon resin disk was nominally 50° (ref. 7) as opposed to 0° on the stainless-steel disk.

Disk and slosh ring baffle. - Since the same tank port would likely function as both the inlet and outlet, consideration was given to improving the plain disk baffle for the case of outflow. The baffle configuration of figure 1(b) was the result. Placing the disk closer to the outlet reduces the volume of liquid beneath the baffle and should delay the time at which vapor is ingested into the outlet during draining. However, during inflow the liquid would more readily flow up the tank wall so a circumferential slosh ring was added. The disk and ring were made of 0.08-centimeter-thick stainless steel. The disk was 1.6 centimeters in diameter, and the ring had an inside diameter of 3.4 centimeters (0.85 tank diameters to approximate slosh rings presently in use). The disk was placed 0.1 centimeter from the tank wall, and the ring was located 2 centimeters above the tank inlet.

180° redirection baffle. - The acrylic plastic 180° redirection baffle (fig. 1(c)) was the inside surface of a toroidal shell bisected perpendicular to its symmetry axis. Both the major and minor radii of the toroid were equal to 0.4 centimeter, giving the baffle an overall diameter of 1.6 centimeters. The location of the baffle was such that its entrance-exit plane was 1 centimeter from the inlet.

135° redirection baffle. - The 135° redirection baffle (fig. 1(d)) resulted from a modification of the 180° baffle. The baffle diameter of 1.6 centimeters was maintained, but the surface beyond a radius of 1.36 centimeters was straightened so that liquid leaving the baffle tangent to that surface would be moving in a direction 135° from its initial velocity. The location of the baffle was chosen so that fluid leaving the baffle would strike the hemisphere normal to its surface.

Perforated plate baffle. - The perforated plate baffle (fig. 1(e)) was a stainless-steel disk that spanned the bottom of the tank at a distance of 1 centimeter from the inlet. The 0.08-centimeter-thick disk contained four holes, each having a diameter equal to

that of the inlet (0.4 cm). The holes were evenly spaced on a 1-centimeter-diameter circle.

Stacked disk baffles. - The stacked disk baffle (fig. 1(f)) was composed of five closely spaced stainless-steel disks. Four of the disks had central holes to allow passage of liquid. The disks were 1.6 centimeters in diameter, 0.08 centimeter thick, and spaced 0.1 centimeter apart. The central holes varied in size in equal increments from 0.8 to 0.2 times the inlet area. The disks were stacked in order of decreasing hole size with distance from the inlet.

The stacked disk and slosh ring baffle was a combination of the previously described stacked disks with the slosh ring from the disk and slosh ring baffle.

Experiment Drop Package

The experiment package shown in figure 2 was a self-contained unit consisting of an experiment tank, a pumping system, a digital clock, and a battery powered electrical system to operate the various components. Indirect frontal illumination of the experiment tank provided sufficient light so that the behavior of the liquid-vapor interface could be recorded with a high-speed 16-millimeter motion-picture camera. An air reservoir, a graduated cylinder, a metering valve, and a solenoid valve all connected with 1-centimeter polyvinyl chloride tubing made up the pumping system shown in figure 3. The volume of the air reservoir was approximately 26 times greater than the largest volume of liquid removed from the graduated cylinder during the transfer operation, implying a supply-pressure decrease of approximately 4 percent during inflow. Time during weightlessness was observed by reading a digital clock having an accuracy of ± 0.01 second. The clock and all other electrical components were operated through a control box and received their power from rechargeable nickel-cadmium cells. The graduated cylinder and clock provided the data necessary to calculate the average flow rate and liquid velocity at the inlet.

RESULTS AND DISCUSSION

Inflow Stability Criterion

For the purposes of this investigation, stable inflow is defined as that in which the incoming liquid accumulates at the inlet end of the tank. Unstable inflow is characterized by (1) geyser-like flow up the center of the tank, (2) globular flow up the center of the tank, or (3) sheet flow up the tank wall with little or no accumulation over the inlet. Entraining of vapor bubbles in the bulk liquid, though not necessarily indicative of

TABLE I. - DATA SUMMARY FOR BAFFLED INFLOW

Baffle	Inflow velocity, cm/sec	Interface stability
None ^a	20.0	Stable, liquid geyser height remains constant
	20.4	Unstable, geyser height slowly increases
	21.0	Unstable, geyser height increases more rapidly
	22.4	Unstable, geyser strikes cylinder wall
Stainless steel disk	32	Stable, hemisphere fills slowly
	42	Stable, hemisphere fills more rapidly
	43	Stable, hemisphere fills more rapidly
	61	Marginal, flow up cylinder wall before filling beneath disk
	70	Unstable, more rapid flow up cylinder wall
	118	Unstable, sheet flow up wall
	143	Unstable, sheet flow up wall
	174	Unstable, all flow is up cylinder wall
Fluorocarbon resin disk	390	Unstable, very rapid flow up cylinder wall
	50	Stable, hemisphere fills
	55	Unstable, geyser forms around disk
	61	Marginal, flow up cylinder wall before filling hemisphere
	65	Marginal, flow up cylinder wall before filling hemisphere
	70	Stable, hemisphere fills before rise up cylinder
Disk and ring	75	Unstable, sheet flow up wall and globules break off from disk
	60	Stable, slow hemisphere filling
	75	Stable, liquid passes ring before filling hemisphere
	83	Unstable, almost no accumulation in hemisphere
180°	93	Unstable, considerable flow along cylinder wall
	70	Stable, trapped bubbles circulating beneath baffle
135°	79	Unstable, considerable flow along cylinder wall
	64	Stable, hemisphere fills beneath baffle
	70	Marginal, developing sheet flow along wall
Perforated plate	80	Unstable, considerable flow up wall
	76	Stable, small droplets strike wall and bubbles circulating beneath baffle
	80	Marginal, increasing flow up cylinder wall
	86	Unstable, rapid flow up wall and large globules moving up tank center
Stacked disks	96	Unstable, rapid flow up wall and large globules moving up tank center
	138	Stable, slow, uniform, hemisphere filling
	148	Stable, increasing flow up wall
	160	Unstable, large liquid volume flows up wall
Stacked disks and ring	175	Unstable, flow along wall with droplets up center
	175	Stable, hemisphere fills before liquid passes ring
	185	Stable, hemisphere fills before liquid passes ring
	199	Stable, hemisphere nearly full before liquid passes ring, interface distorted, small drops break away
	220	Stable, hemisphere nearly full before liquid passes ring, interface distorted, small drops break away
	239	Marginal, more rapid rise up wall, bubbles being trapped
	244	Unstable, large globules move up center, many bubbles trapped
	260	Unstable, large geyser strikes wall

^aFrom ref. 5.

instability, is considered unsatisfactory. Such vapor bubbles withdrawn from the tank could result in intermittent operation of engines, attitude control thrusters, or life support systems.

A summary of the data for this program is presented in table I. The baffle type, the average fluid velocity at the inlet, and general comments on the fluid behavior are given. The data presented for the unbaffled tank were taken from that collected for reference 5. The tank and inlet were the same as those used in the baffled inflow investigation. Note that the critical inflow velocity for the unbaffled tank was found to be approximately 20 centimeters per second.

Inflow With Baffles

Plain disk baffles. - Liquid inflow to a tank containing the plain stainless-steel disk baffle is presented photographically in figure 4. The sequence in part (a) of the figure shows stable inflow to the tank at 43 centimeters per second. The liquid struck the disk, filled the volume between the three support posts, and then continued to fill the hemisphere. The transition to unstable inflow occurred for an inflow velocity between 60 and 70 centimeters per second. Thus, the critical inflow velocity of 20 centimeters per second for the unbaffled tank is increased three to three and one-half times by using the plain disk baffle. Unstable behavior (fig. 4(b)) was characterized by liquid striking the disk and flowing radially outward from it followed by flow up the cylinder wall. Little or no liquid accumulated over the inlet. Inflow velocities greater than 140 centimeters per second were sufficient to show liquid accumulation and subsequent loss at the vent end of the tank within the 2-second drop period.

Figures 5 and 6 illustrate the results for inflow to a tank containing the fluorocarbon resin disk. For liquid inflow velocities below approximately 50 centimeters per second, the filling process remained stable as shown in figure 5(a). The behavior of the liquid was similar to that for stable inflow to a tank containing a stainless-steel disk. For inflow velocities between approximately 50 and 55 centimeters per second, a transition to unstable inflow took place. This was about 2.5 times the critical inflow velocity for an unbaffled tank. The sequence of photographs in figure 5(b) shows the unstable behavior in which the liquid wet around the disk and continued flowing as a column toward the vent. This behavior was not observed with the stainless-steel disk at any inflow velocity used. Stable inflow was again observed for the fluorocarbon disk at an inflow velocity of approximately 70 centimeters per second (fig. 6(a)). A second transition to unstable inflow occurred for an inflow velocity between 70 and 75 centimeters per second. As figure 6(b) indicates, the unstable behavior for an inflow velocity above 70 centimeters per second was similar to that observed for the stainless-steel disk in which the liquid flowed radially outward from beneath the disk.

The major difference between flow into tanks with the steel and fluorocarbon disks was the apparent region of stable inflow for the fluorocarbon disk bounded by unstable inflow at lower as well as higher inflow velocities. A second difference was the formation of a liquid geyser following envelopment of the fluorocarbon disk by the liquid at a moderate inflow velocity. In regard to the contact angle difference, it would seem that the stainless-steel disk should have been more susceptible than the fluorocarbon disk to wetting and envelopment by the liquid with subsequent geyser formation. However, in all but one run with the steel disk, the top remained dry until at least 2.5 cubic centimeters of liquid had entered the tank. The actual volume was probably larger, but in most cases the view of the top of the disk was obscured by liquid on the tank wall and the time of coverage could not be determined.

Disk and slosh ring baffle. - Figure 7 depicts the results of inflow to a tank containing the disk near the inlet plus the slosh ring. During stable inflow (fig. 7(a)) the hemisphere was rapidly wetted up to the slosh ring. The hemisphere continued to fill, and the liquid vapor interface approached a hemispherical shape bounded by the slosh ring. The liquid eventually wet the top of the ring and filled the corner between the ring and cylindrical tank wall. Motion of the interface following complete filling of the hemisphere could not be observed because of insufficient time in weightlessness. Presumably the tank would continue to fill in a stable manner with a hemispherical liquid vapor interface moving uniformly toward the vent. The transition to unstable inflow took place for an inflow velocity between 75 and 84 centimeters per second. The maximum inflow rate for stable filling using the disk plus ring baffle was slightly higher than that using the plain disks. It was about four times the critical inflow velocity for an unbaffled tank. During unstable inflow (fig. 7(b)), the liquid wet around the slosh ring and flowed up the cylinder without an appreciable accumulation in the hemisphere.

180° redirection baffle. - Figure 8 presents the results of inflow to a tank containing the 180° redirection baffle. During stable inflow (fig. 8(a)), the liquid struck the baffle and spread over the toroidal surface as it was directed toward the inlet. The liquid then left the baffle and moved toward the inlet in the form of a cylindrical shell. After striking the hemisphere, some of the liquid rose up the tank wall while most of the incoming liquid accumulated over the inlet. The transition to unstable inflow occurred for an inflow velocity between 70 and 79 centimeters per second, about 3.75 times the critical inflow velocity for an unbaffled tank. During the unstable inflow pictured in figure 8(b), nearly all of the incoming liquid flowed up the tank wall after striking the hemispherical bottom. A disadvantage of using this baffle was that vapor bubbles tended to become trapped beneath the baffle during stable inflow.

135° redirection baffle. - The 135° redirection baffle would maintain stable liquid inflow up to about 70 centimeters per second. Figure 9(a) illustrates stable inflow to a tank containing this baffle. The liquid striking the baffle spread and was directed through

135°. After leaving the baffle, the liquid struck the hemisphere perpendicular to its surface. Unlike the 180° baffle, the 135° baffle did not trap vapor bubbles beneath it. For unstable inflow (fig. 9(b)) the volume beneath the baffle was partially filled before the incoming liquid flowed up the cylinder wall. Using either of the redirection baffles allowed stable inflow at about 3.5 times the critical inflow velocity for an unbaffled tank. This is the same order of improvement obtained by using the disk baffles.

Perforated plate baffle. - Stable inflow to a tank containing the perforated plate baffle is shown in figure 10(a). The liquid struck the plate and covered it before wetting the hemisphere walls. Accumulation beneath the plate continued and some liquid eventually wet through one of the four holes and covered the top of the plate. Vapor bubbles trapped beneath the plate were occasionally carried through the holes but many bubbles remained in the bulk liquid between the plate and the inlet.

Inflow was unstable (fig. 10(b)) above an inflow velocity of approximately 80 centimeters per second. The critical inflow velocity was, therefore, about four times that of an unbaffled tank. During unstable inflow the liquid quickly covered the bottom of the plate, wet through the holes, and covered the top of the plate. The flow then continued toward the vent as a film on the cylinder wall and as globules from the flow through one of the holes. In both stable and unstable inflow it was noted that the flow was not uniformly distributed among the four holes in the plate. The majority of the flow appeared to proceed from the hole through which the liquid first penetrated.

Stacked disk baffles. - The performance of the stacked disk baffle was significantly better than that of the baffles previously discussed. The critical inflow velocity was between 150 and 160 centimeters per second or 7.5 to 8 times the critical velocity for an unbaffled tank. Figure 11(a) illustrates stable inflow to the tank. The spaces between the disks were rapidly filled before the hemispherical bottom of the tank was covered. Liquid emerging from between pairs of disks combined to form a sheath enclosing the baffle assembly. Filling of the hemisphere proceeded from the base of the baffle but was not so rapid as to continue flowing up the cylinder wall. When sufficient liquid had flowed into the tank, a nearly hemispherical liquid vapor interface closed over the top of the baffle. As filling continued, the interface moved uniformly toward the vent end of the tank. Figure 11(b) shows the case of unstable inflow in which some liquid accumulated around the baffle while most of it flowed as a film along the cylinder wall.

Figure 12 shows stable and unstable inflow for a tank containing the stacked disks plus the slosh ring. The critical inflow velocity for this arrangement was in the range 220 to 240 centimeters per second making it 11 to 12 times better than the unbaffled tank. During stable filling at high flow rates the interface shape was distorted from hemispherical and was continually changing. During unstable inflow, liquid flow along the cylinder wall was accompanied by liquid globules moving up the center of the cylinder.

Pressure Drop Across Baffles

Tests using the stacked disks, the perforated plate, and the disk from the disk and ring were conducted to determine what portion of the pressure drop across the tank inlet - baffle combination was due to the baffle. It was found that the perforated plate baffle produced the largest pressure drop for a given flow rate followed by the disk from the disk and ring, and the stacked disks. In order to produce a given flow rate, the driving pressure ahead of the inlet for a tank containing the perforated plate had to be approximately 16 percent higher than that for the empty tank.

CONCLUDING REMARKS

An experimental investigation was conducted in a weightless environment to determine the effect of several baffle configurations on the critical inflow velocity of a liquid flowing into an initially empty hemispherically ended, cylindrical tank. Figure 13 is a graphic comparison of the effectiveness of the various baffles in increasing the critical inflow velocity. As indicated, most of the baffles provided a three- to fourfold increase in the un baffled tank's critical inflow velocity. One of the eight configurations tested, the stacked disk plus slosh ring baffle, provided up to a twelvefold improvement. Liquid flowing along the cylindrical tank wall with little or no accumulation at the inlet was characteristic of unstable inflow for all cases. The perforated plate and stacked disk plus slosh ring baffles also displayed unstable globular liquid flow up the center of the tank. Vapor entrainment in the bulk liquid collected in the tank was observed for the 180° redirection and perforated plate baffles during stable inflow. The baffles that had the largest effect on the critical inflow velocity were those which diffused the liquid the most upon entering the tank.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, May 1, 1972,
113-31.

APPENDIX - TEST FACILITY

The experimental data for this study were obtained in the Lewis 2.2-Second Zero-Gravity Facility. A schematic diagram of this facility is shown in figure 14. The facility consists of a building 6.4 meters (21 ft) square by 30.5 meters (100 ft) tall. Contained within the building is a drop area 27 meters (89 ft) long with a cross section of 1.5 by 2.75 meters (5 by 9 ft).

The service building has, as its major elements, a shop and service area, a calibration room, and a controlled environment room. Those components of the experiment that require special handling are prepared in the controlled environment room of the facility. This air-conditioned and filtered room contains an ultrasonic cleaning system and the laboratory equipment necessary for handling test liquids.

Mode of operation. - A 2.2-second period of weightlessness is obtained by allowing the experiment package to free fall from the top of the drop area. In order to minimize drag on the experiment package, it is enclosed in a drag shield, designed with a high ratio of weight to frontal area and a low drag coefficient. The relative motion of the experiment package with respect to the drag shield during a test is shown in figure 15. Throughout the test the experiment package and drag shield fall freely and independently of each other; that is, no guide wires, electrical lines, etc., are connected to either. Therefore, the only force acting on the freely falling experiment package is the air drag associated with the relative motion of the package within the enclosure of the drag shield. This air drag results in an equivalent gravitational acceleration acting on the experiment, which is estimated to be below 10^{-5} g.

Release system. - The experiment package, installed within the drag shield, is suspended at the top of the drop area by a highly stressed music wire which is attached to the release system. This release system consists of a double-acting air cylinder with a hard steel knife attached to the piston. Pressurization of the air cylinder drives the knife edge against the wire which is backed by an anvil. The resulting notch causes the wire to fail and smoothly release the experiment. No measurable disturbances are imparted to the package by this release procedure.

Recovery system. - After the experiment package and drag shield have traversed the total length of the drop area and have been decelerated in a 2.2-meter (7-ft) deep container filled with sand, they are recovered. The deceleration rate (averaging 15 g's) is controlled by selectively varying the tips of the deceleration spikes mounted on the bottom of the drag shield (fig. 14). At the time of impact of the drag shield in the decelerator container, the experiment package has traversed the vertical distance within the drag shield (compare figs. 15(a) and (c)).

Procedure. - Before assembling the flow components, the tank and all the flow lines were first cleaned in an ultrasonic cleaner to assure that the properties of the test

liquids would not be affected by contaminants. The parts were then rinsed with distilled water and dried in a warm air dryer. All parts were assembled and mounted in the package.

The flow lines were filled with liquid and activated several times to remove any air that may have been trapped in the lines. The system was checked for leaks; a normal-gravity calibration test was conducted to set the desired flow rate; and the timer was set at a predetermined time increment. This set the time when the solenoid valve would open and initiate inflow of liquid to the experiment tank shortly after the experiment package was released.

The desired quantity of test liquid was then placed in the graduated cylinder and nitrogen gas was supplied to the reservoir at the required pressure. The camera was then loaded, and the experiment package was balanced about its horizontal axes and positioned in the prebalanced drag shield. The wire support was then attached to the experiment package through an access hole in the drag shield (see fig. 15). Properly sized spike tips were installed on the shield. Then the drag shield, with the experiment package inside, was hoisted to the predrop position at the top of the facility (fig. 14). The wire support was attached to the release system, and the entire assembly was suspended from the wire. After final electrical checks and switching to internal power, the system was released. After completion of the test, the experiment package and drag shield were returned to the preparation area.

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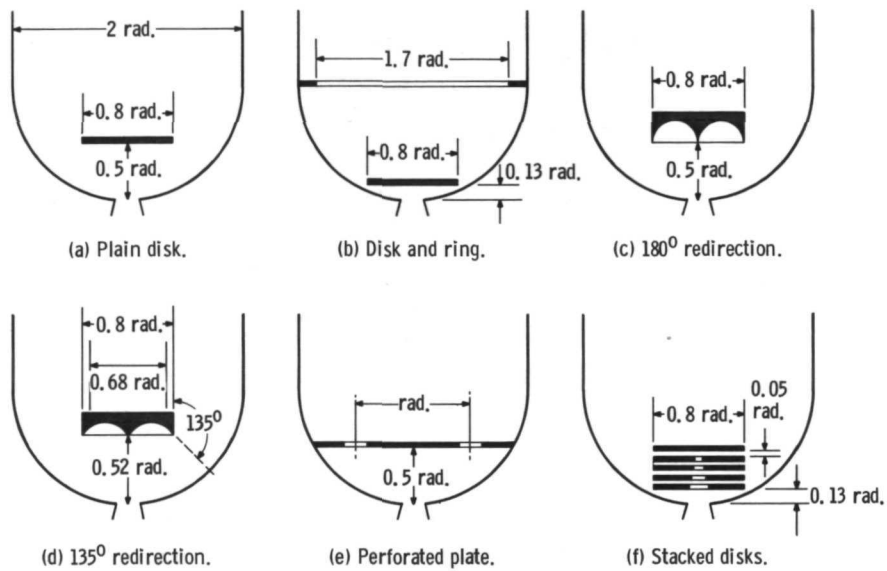


Figure 1. - Inflow baffle cross sections.

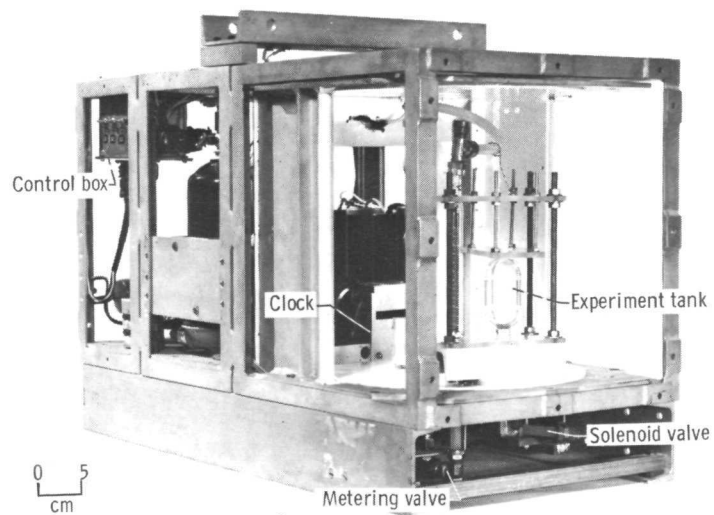
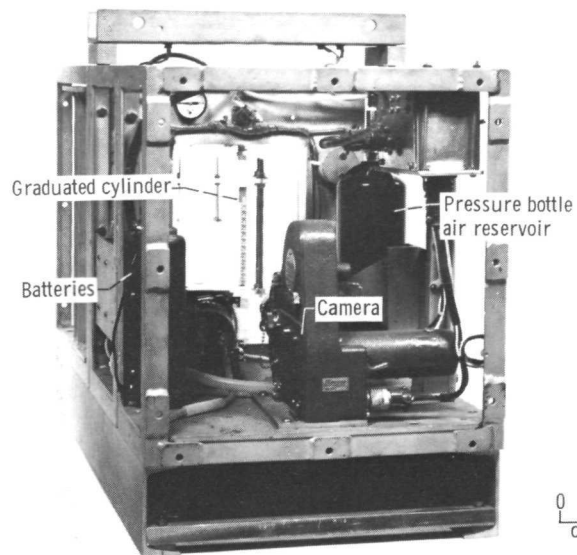


Figure 2. - Experiment package.

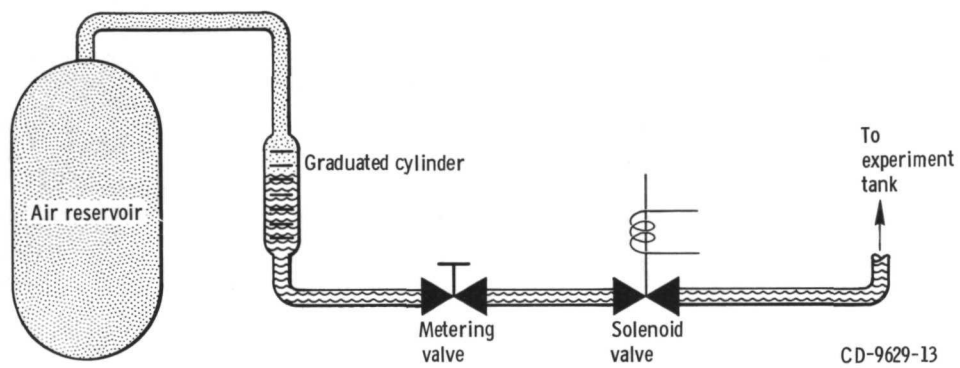
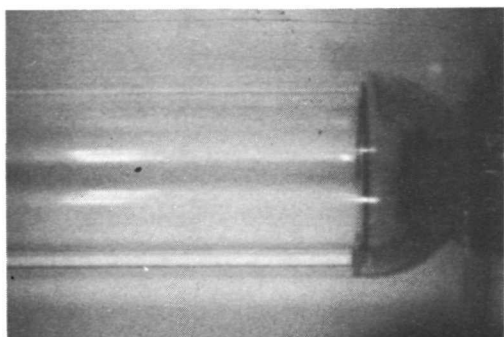
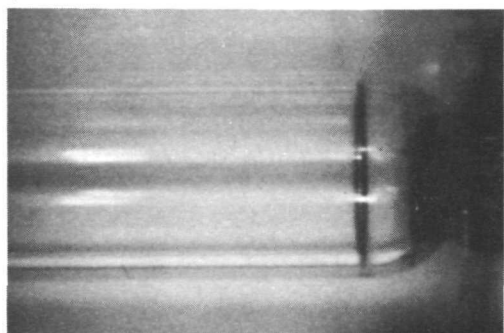


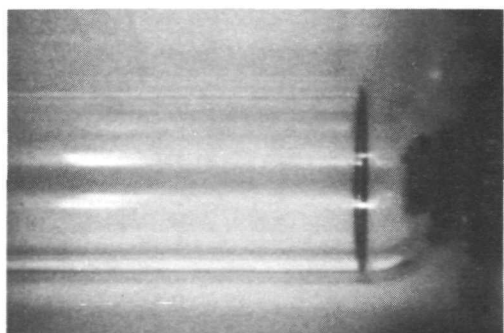
Figure 3. - Pumping system schematic.



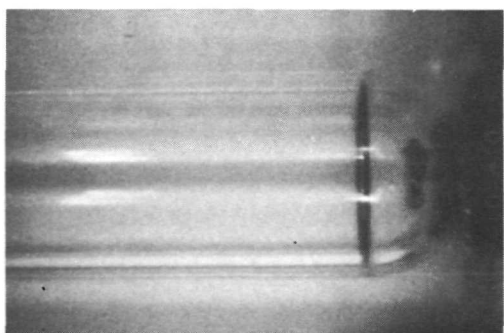
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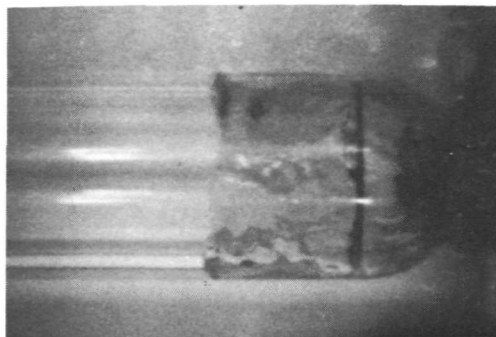


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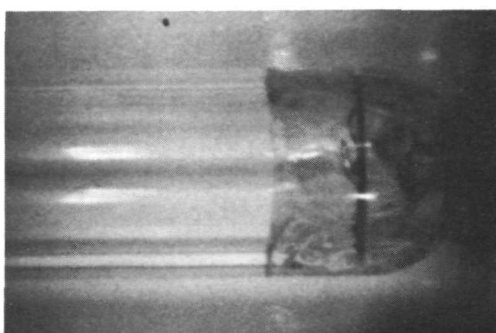


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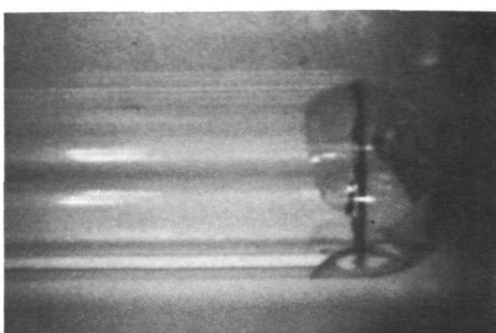
(a) Stable inflow; inlet velocity, 43 centimeters per second.



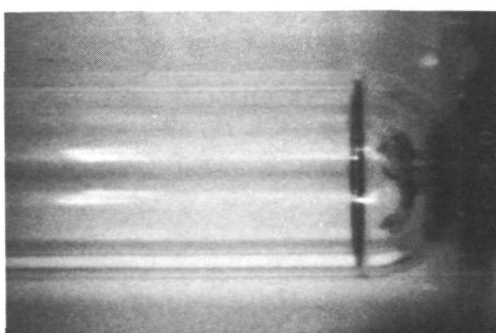
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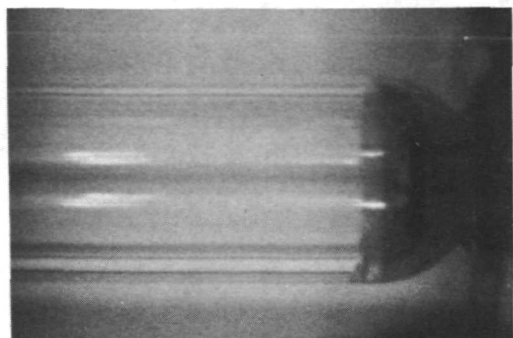


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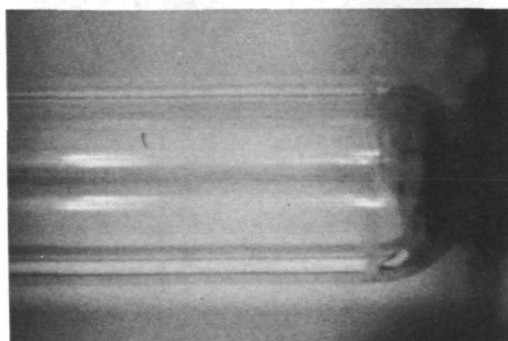


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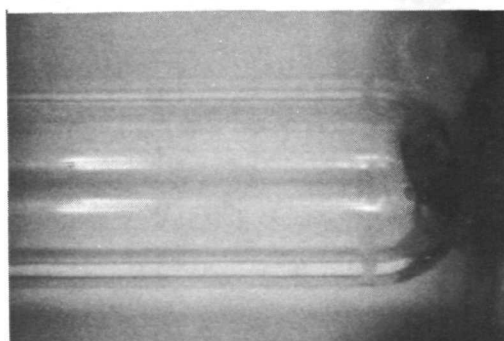
(b) Unstable inflow; inlet velocity, 70 centimeters per second.
Figure 4. - Inflow to tank containing plain stainless steel disk baffle.



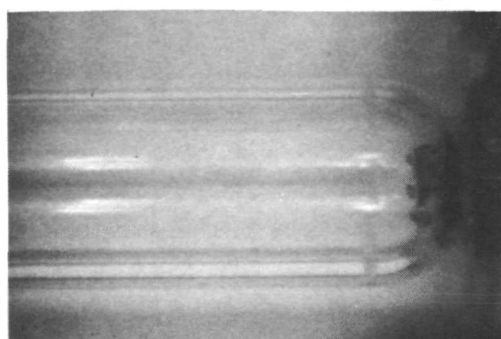
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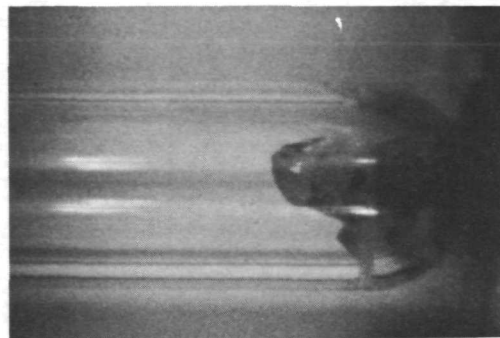


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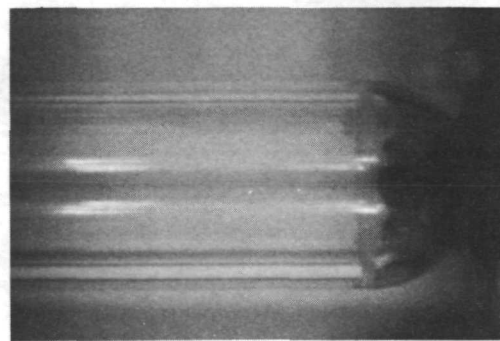


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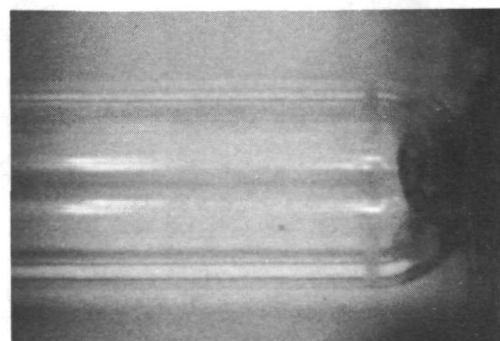
(a) Stable inflow; inlet velocity, 50 centimeters per second.



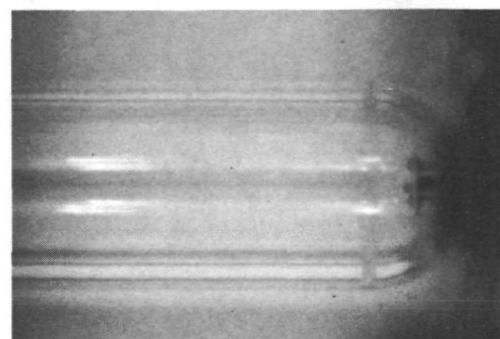
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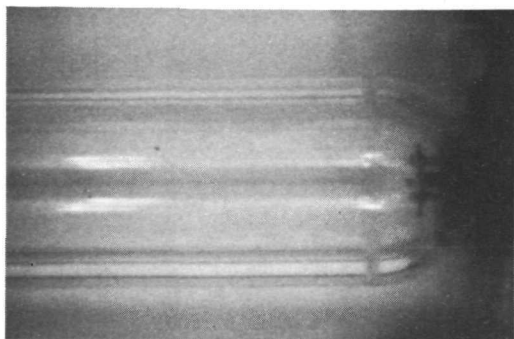


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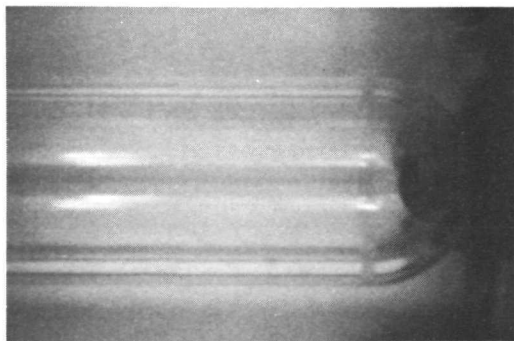
Time from start of flow, sec

(b) Unstable inflow; inlet velocity, 55 centimeters per second.

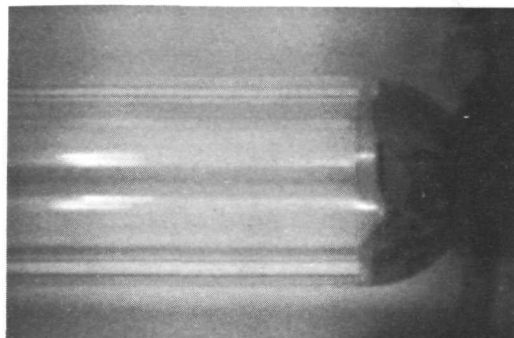
Figure 5. - Inflow to tank containing plain fluorocarbon disk baffle.



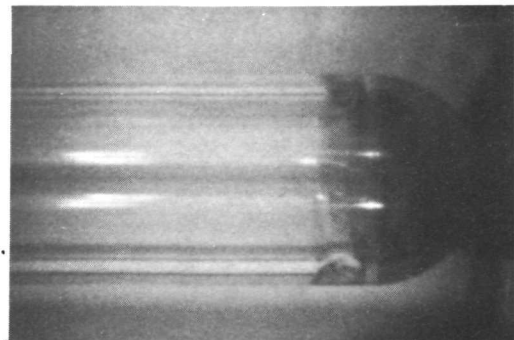
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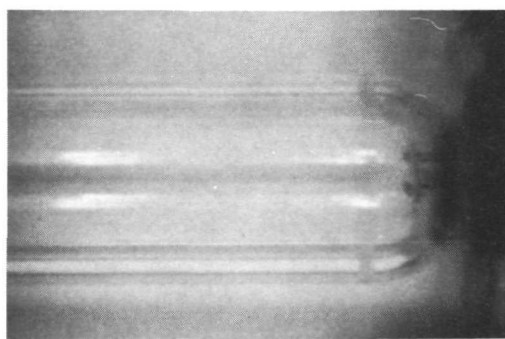


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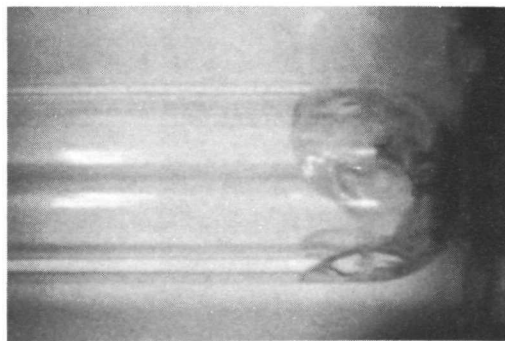


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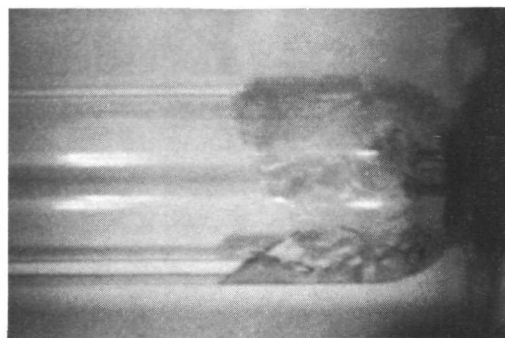
(a) Stable inflow; inlet velocity, 70 centimeters per second.



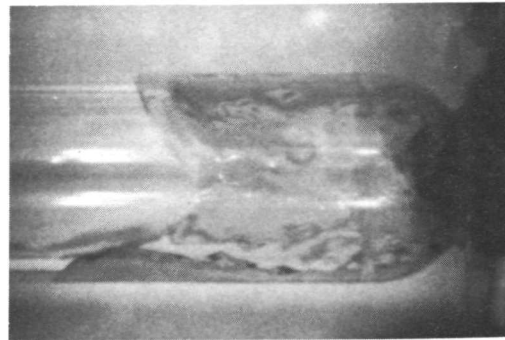
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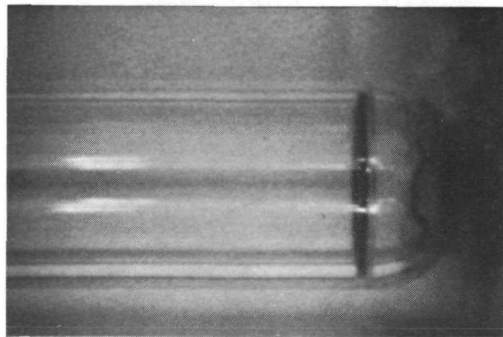


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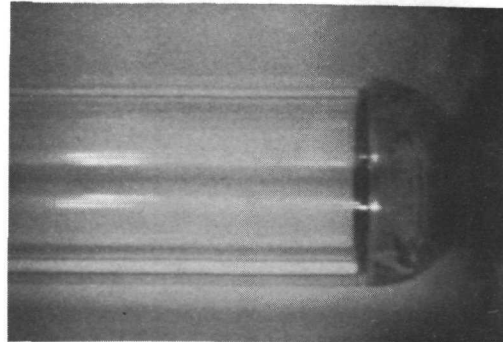
Time from start of flow, sec

(b) Unstable inflow; inlet velocity, 75 centimeters per second.

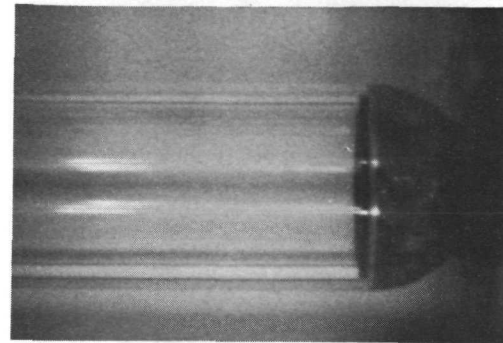
Figure 6. - Inflow to tank containing plain fluorocarbon disk baffle.



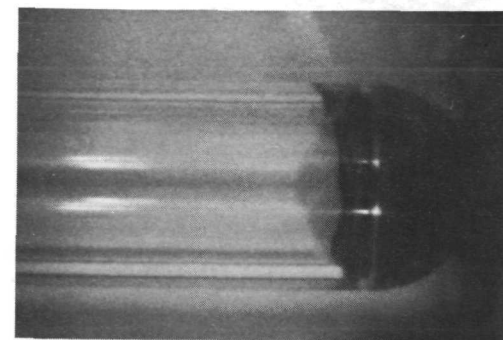
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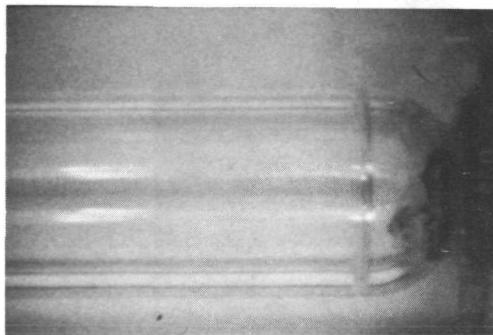
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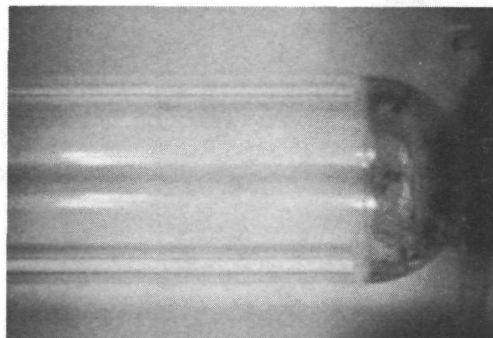
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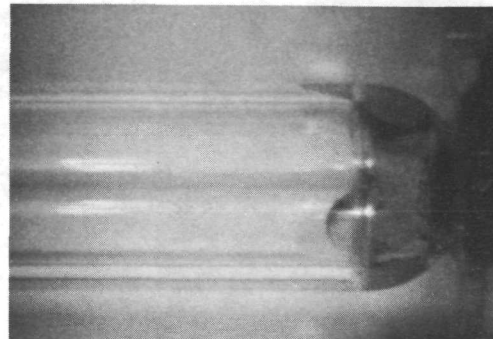
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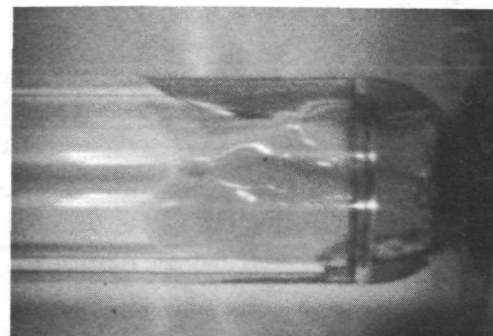
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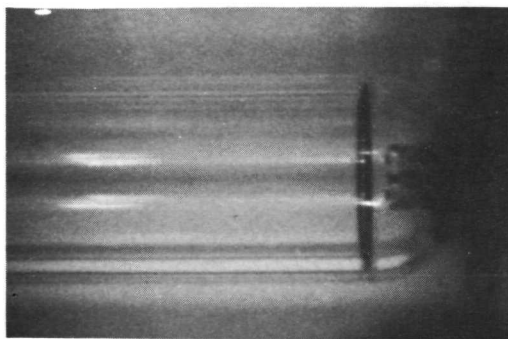
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Time from start of flow, sec

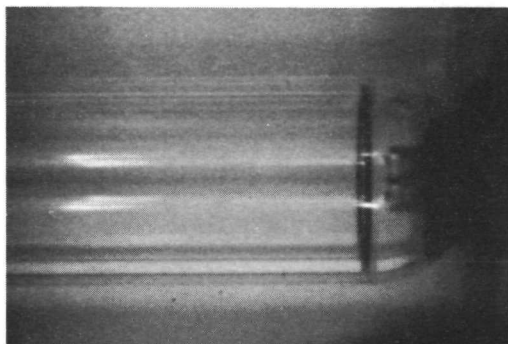
(a) Stable inflow; inlet velocity, 75 centimeters per second.

(b) Unstable inflow; inlet velocity, 83 centimeters per second.

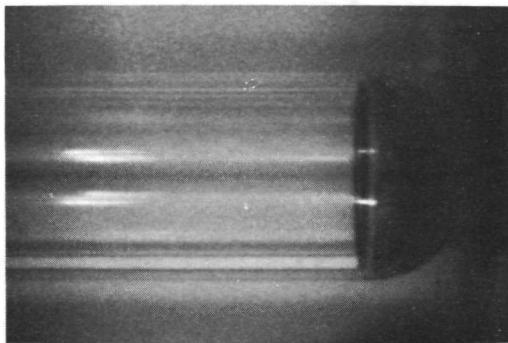
Figure 7. - Inflow to tank containing disk and slosh ring baffle.



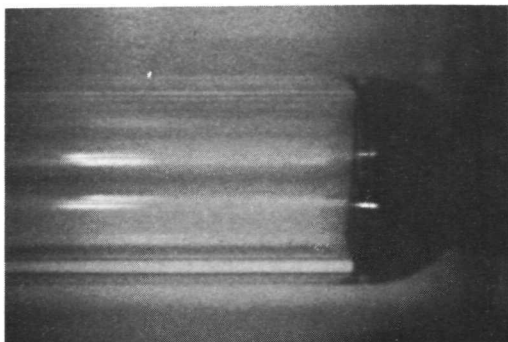
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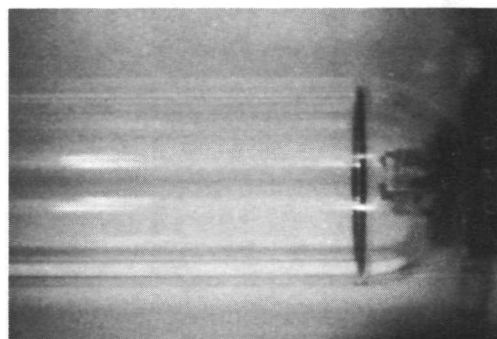


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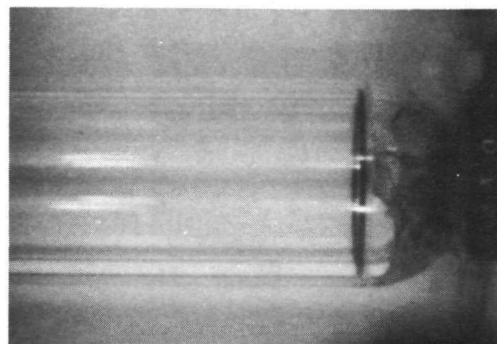


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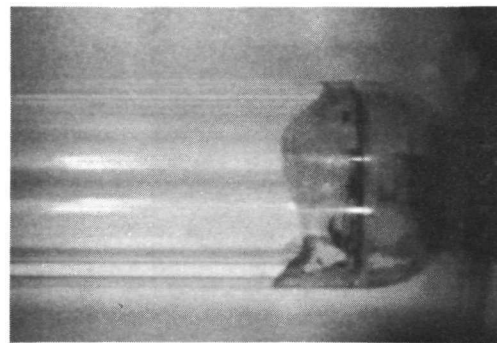
(a) Stable inflow; inlet velocity, 70 centimeters per second.



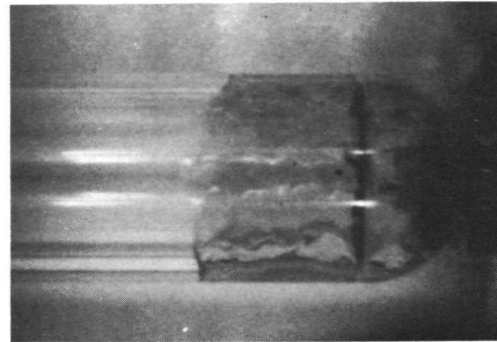
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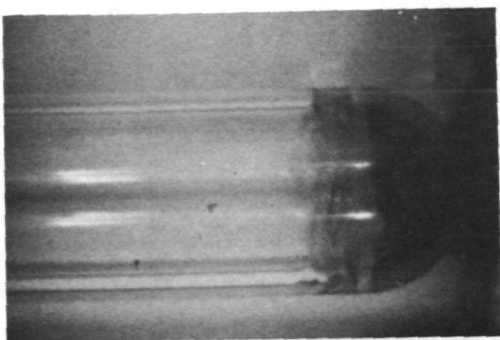
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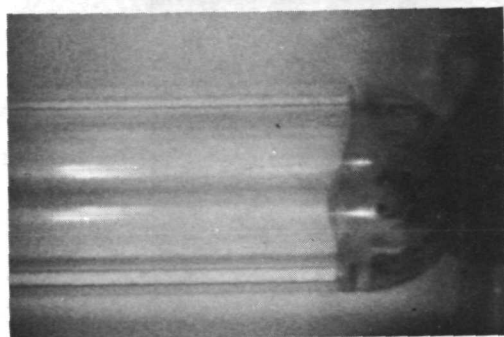
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(b) Unstable inflow; inlet velocity, 79 centimeters per second.

Figure 8. - Inflow to tank containing 180° redirection baffle.



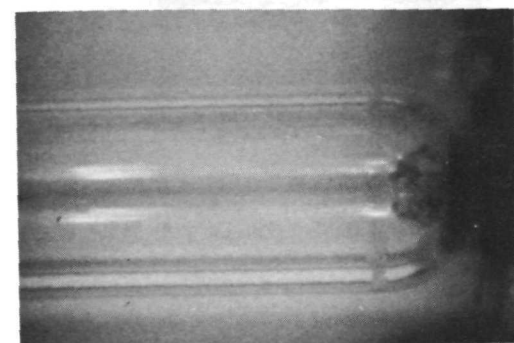
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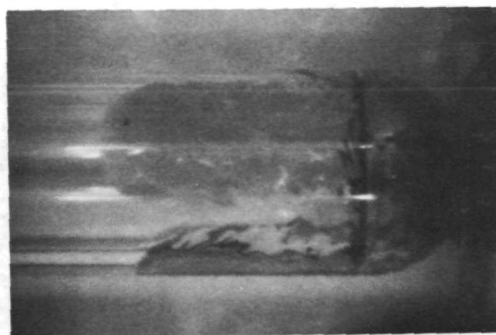


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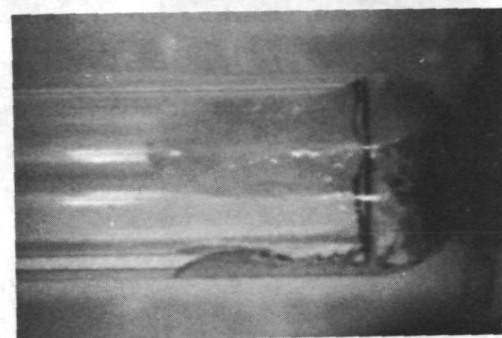


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(a) Stable inflow; inlet velocity, 64 centimeters per second.



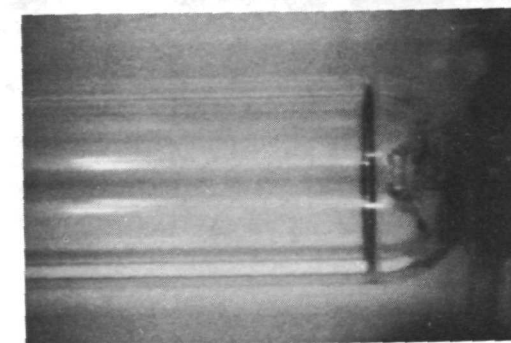
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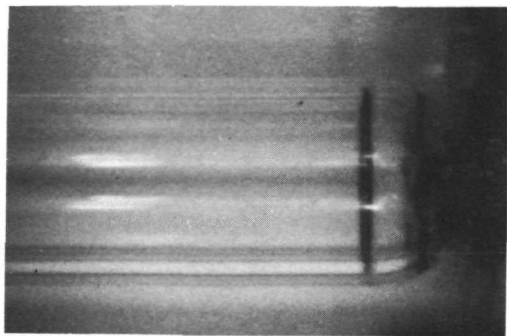
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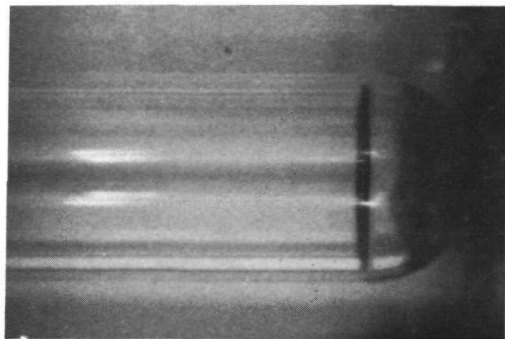
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(b) Unstable inflow; inlet velocity, 80 centimeters per second.

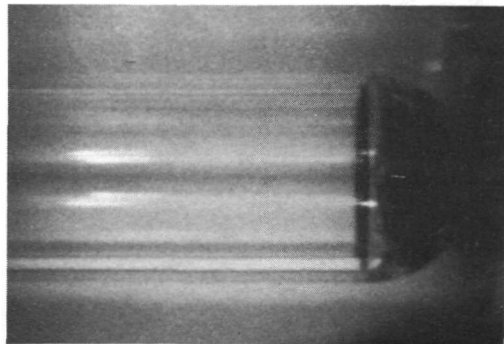
Figure 9. - Inflow to tank containing 135° redirection baffle.



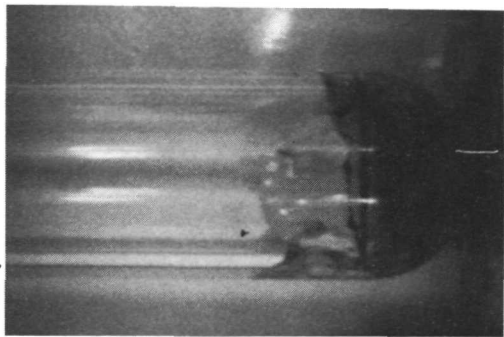
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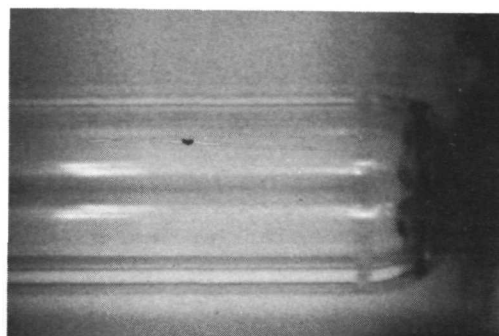


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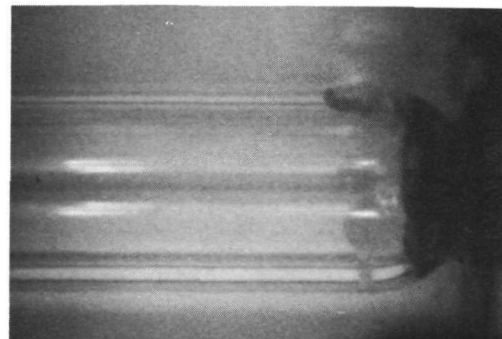


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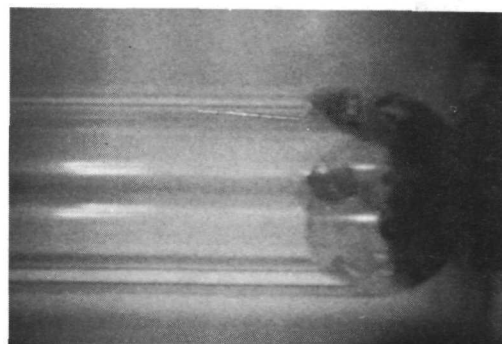
(a) Stable inflow; inlet velocity, 80 centimeters per second.



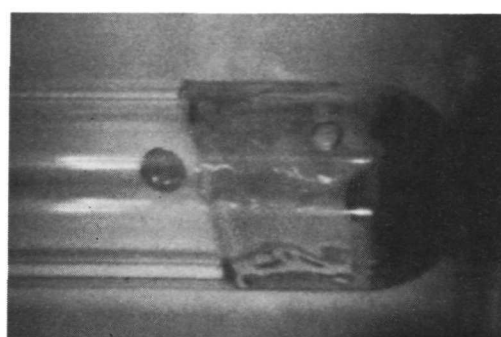
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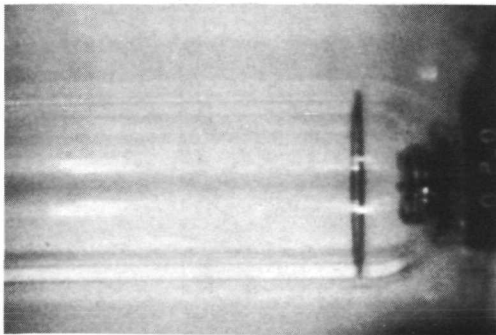


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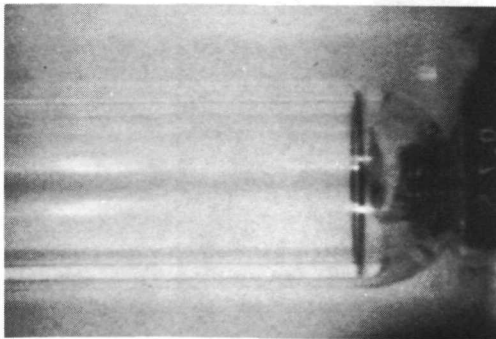


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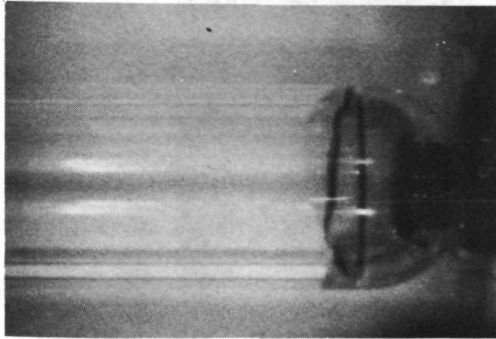
(b) Unstable inflow; inlet velocity, 86 centimeters per second.
Figure 10. - Inflow to tank containing perforated plate baffle.



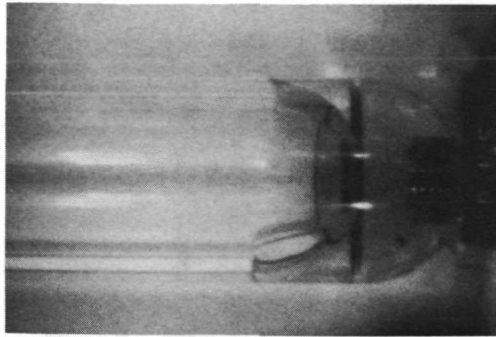
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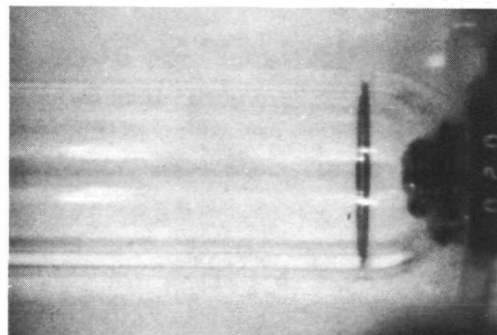


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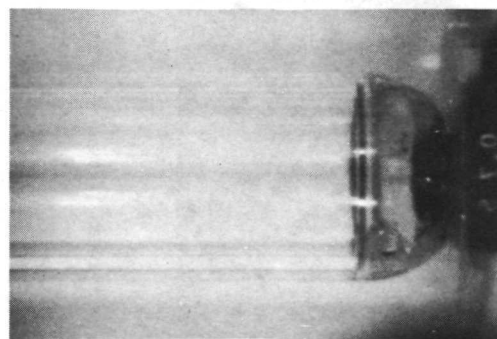


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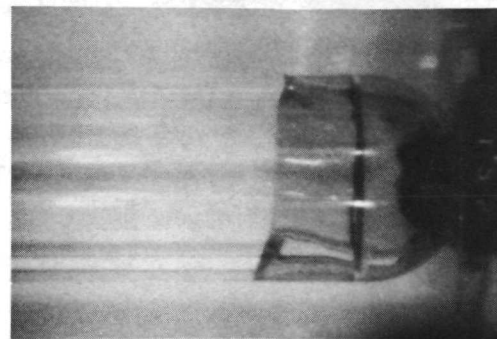
(a) Stable inflow; inlet velocity, 138 centimeters per second.



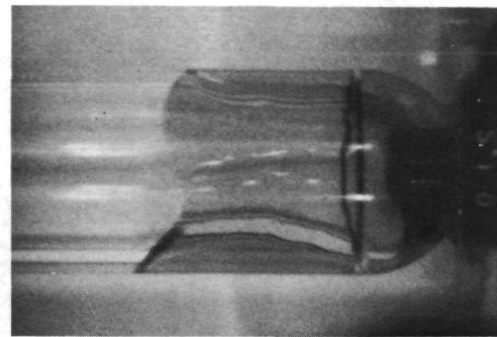
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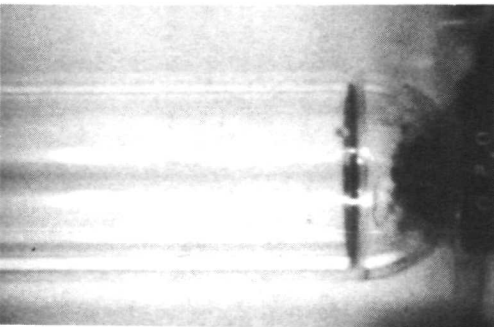
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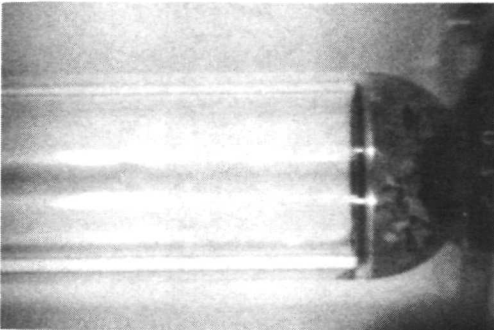
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(b) Unstable inflow; inlet velocity, 160 centimeters per second.

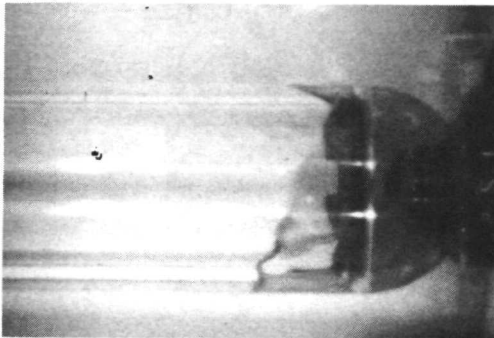
Figure 11. - Inflow to tank containing stacked disk baffle.



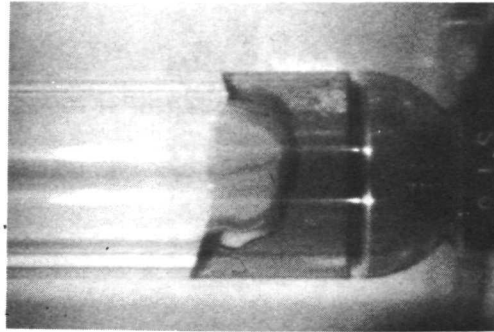
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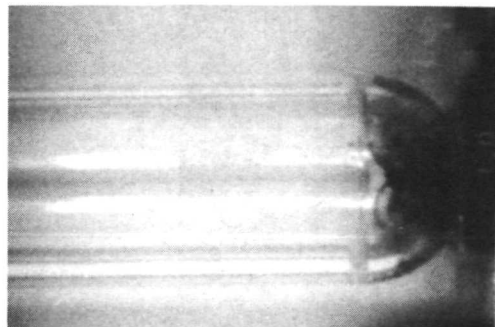


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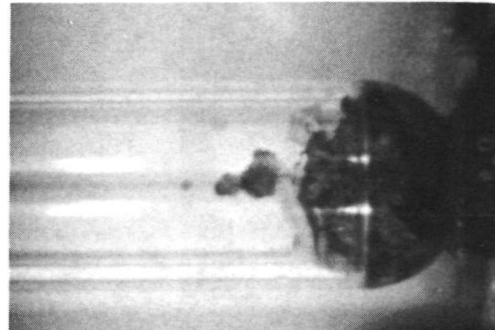


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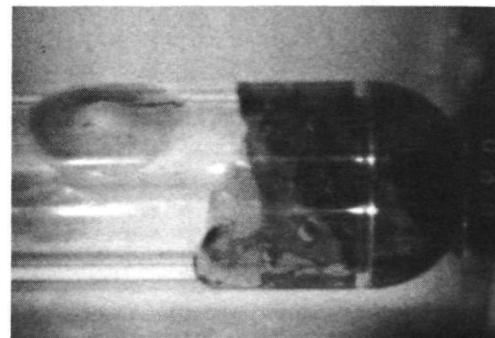
(a) Stable inflow; inlet velocity, 220 centimeters per second.



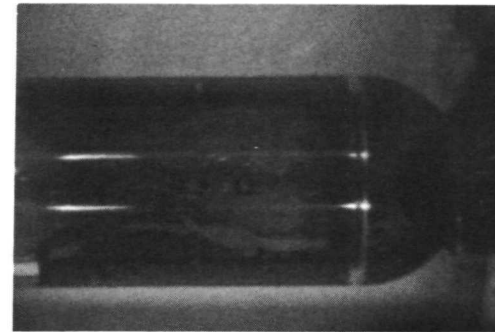
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Time from start of flow

(b) Unstable inflow; inlet velocity, 244 centimeters per second.

Figure 12. - Inflow to tank containing stacked disks plus slosh ring.

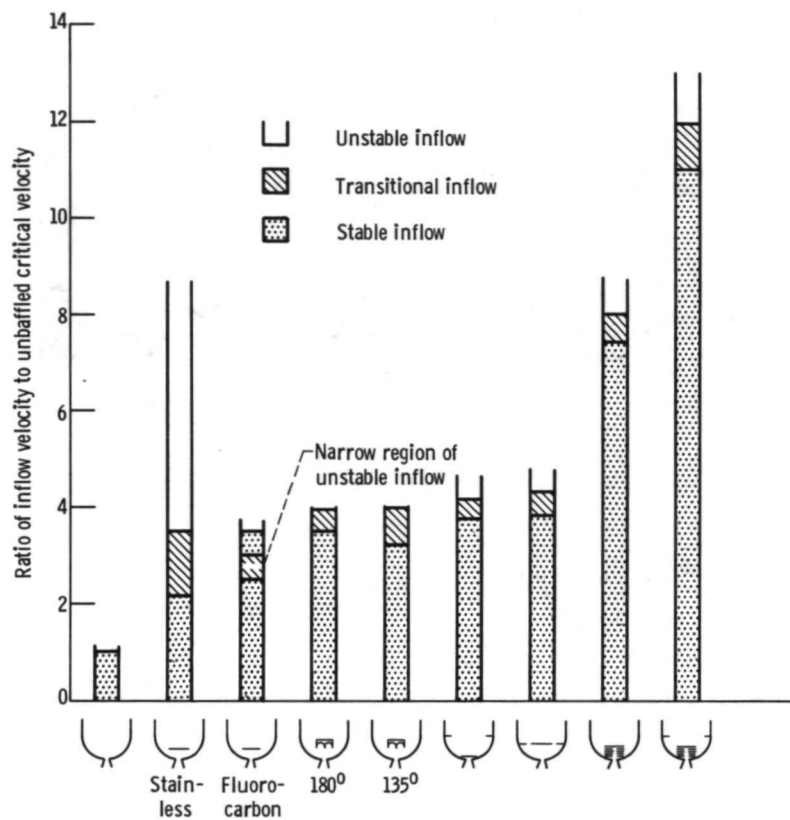


Figure 13. - Comparison of inflow baffle effectiveness.

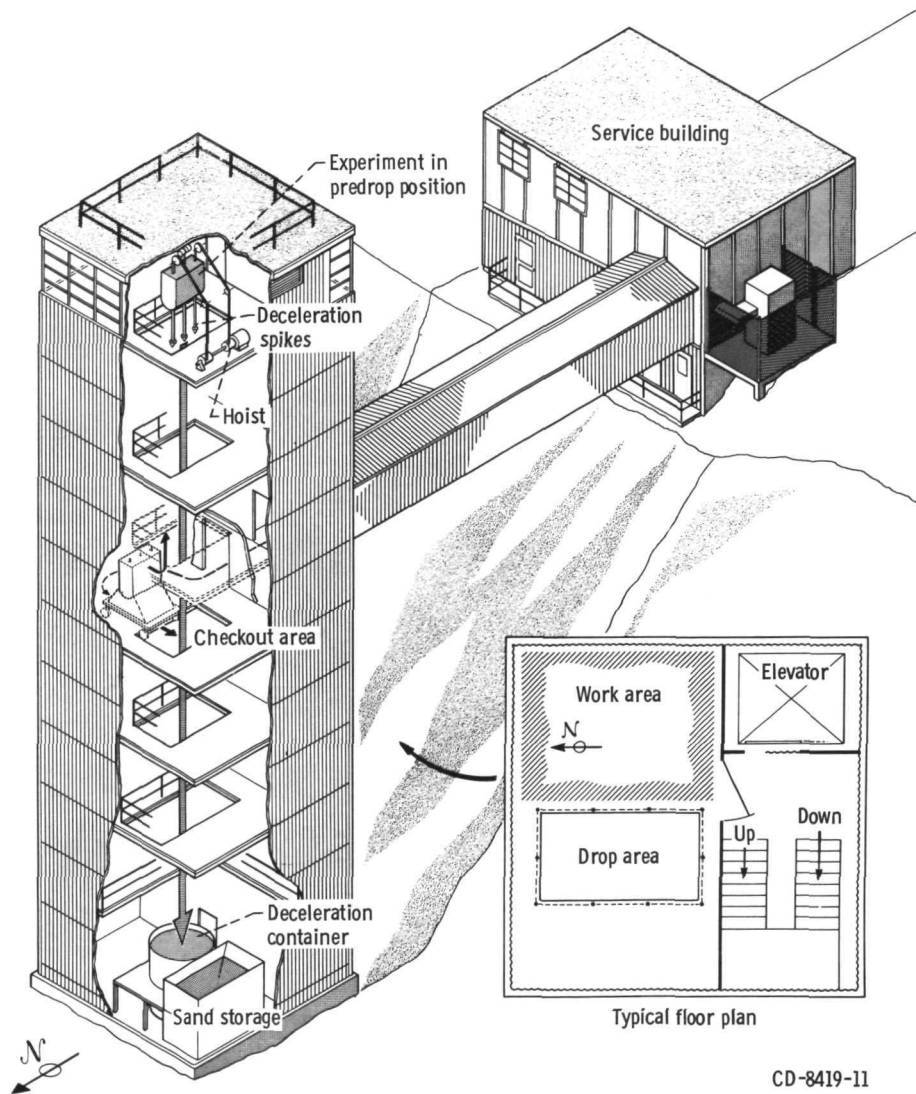
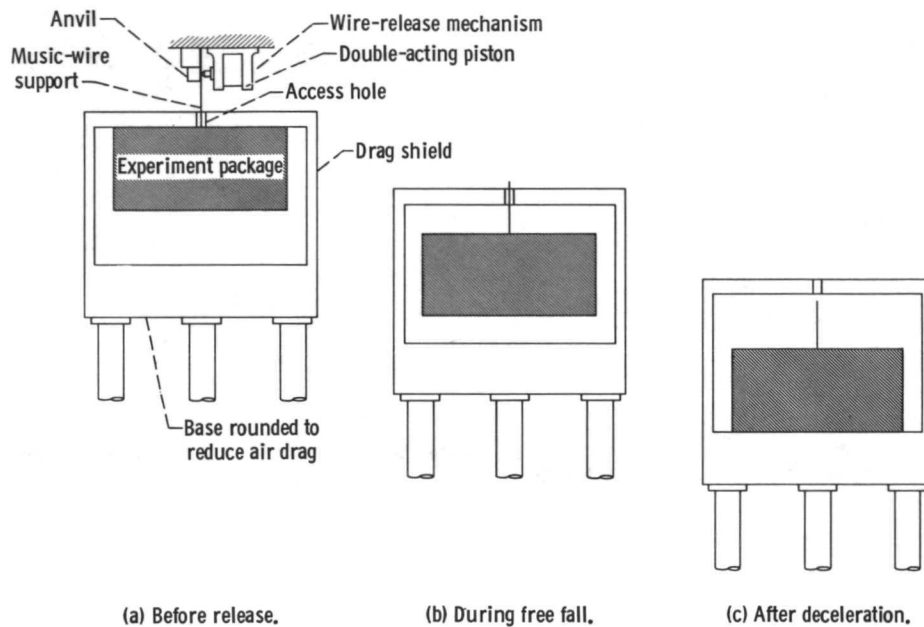


Figure 14. - 2.2-Second Zero Gravity Facility.



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Figure 15. - Position of experiment package and drag shield before, during, and after test drop.

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